The $s\bar{s}$ and $K\bar{K}$ nature of $f_0(980)$ in D_s decays

A. Deandrea[(a)], R. Gatto[(b)], G.Nardulli[(c)], A.D. Polosa[(d)] and N. A. Törnqvist[(d)]

(a) Institut de Physique Nucléaire, Université Lyon I, 43, bd du 11 Novembre 1918, F–69622 Villeurbanne Cedex, France

(b) Département de Physique Théorique, Université de Genève, 24 quai E.-Ansermet, CH-1211 Genève 4, Switzerland

(c) Dipartimento di Fisica, Università di Bari and INFN Bari, via Amendola 173, I-70126 Bari, Italy

(d) Physics Department, POB 9, FIN–00014, University of Helsinki, Finland

(December, 2000)

We examine the $D_s \to f_0(980)\pi$ amplitude through a constituent quark-meson model, incorporating heavy quark and chiral symmetries, finding a good agreement with the recent E791 data analysis of $D_s \to 3\pi$ via $f_0(980)$. The $f_0(980)$ resonance is considered at the moment of production as an $s\bar{s}$ state, later evolving to a superposition of mainly $s\bar{s}$ and $K\bar{K}$. The analysis is also extended to the more frequent process $D_s \to \phi\pi$.

Pacs numbers: 13.25.Ft, 12.39.Hg, 14.40.Cs
LYCEN-2000-132
UGVA-DPT/2000-11-1090
HIP-2000-65/TH

(i) Introduction

The scalar mesons have remained a controversial enigma since a long time. There is today no consensus as to the true nature of especially the lightest scalars, the σ, $f_0(980)$ and $a_0(980)$. Are these $q\bar{q}$ [1], $\pi\pi$ [2], $K\bar{K}$ bound state by hyperfine interaction [3] or multi-quark [4] states? Is the expected scalar gluonium state [5,6] present among these mesons, either as the dominant component, or through a small mixing?

These are fundamental questions of great importance in particle physics. The mesons with vacuum quantum numbers are known to be crucial for a full understanding of the symmetry breaking mechanisms in QCD, and presumably also for confinement. The light σ, near 500 MeV in mass and with a large width of the same order of magnitude, has reappeared on the scene (it has been on the short list of PDG since 1996 [7,8]), and a growing number of analyses, using more sophisticated theoretical techniques, now find this elusive meson in $\pi\pi \to \pi\pi$, where its presence is almost hidden because of the Adler zero (in production experiments the σ appears more clearly). Recently, in June 2000, a conference, entirely devoted to the σ, was held in Kyoto [9], and many new analyses of old data were presented, showing a wide agreement on a σ pole near $m - i\Gamma/2 = 500 - i250$ MeV.

Experiments studying charm decay to light hadrons are opening up a new unique experimental window for understanding light meson spectroscopy, and especially the controversial scalar mesons. The scalars are abundantly produced in these decays, and in the recent E791 experiment [10] the σ contributes 46% of the $D \to 3\pi$, and $f_0(980)$ over 50% of the $D_s \to 3\pi$ Dalitz plot [11].

D_s decays are particularly interesting, since with the Cabibbo favored $c \to s$ transition and the dominant spectator mechanism one expects the final state to be dominated by $s\bar{s}$ states. This mechanism is supported by the fact that, in D_s decay, the well known nearly-$s\bar{s}$ vector state, the $\phi(1020)$, is abundantly produced, and one consequently expects that also the related scalar $s\bar{s}$ state should appear strongly. Since the $f_0(980)$ is produced copiously in D_s decay, this supports the picture of a large $s\bar{s}$ component in its wave function.

Previously this predominant $s\bar{s}$ nature of the $f_0(980)$ has been supported by the radiative decay $\phi \to f_0(980)\gamma$ [12] and by unitarized quark models [1], although being just below the $K\bar{K}$ threshold it should also have a large component of virtual $K\bar{K}$ in its wave function.

In this paper we shall assume that both the $\phi(1020)$ and the $f_0(980)$ are predominantly $s\bar{s}$ states, or at least that when they are produced in D_s decay, the production is via the $s\bar{s}$ component. After production the $s\bar{s}$ core of $f_0(980)$ induces a virtual cloud of $K\bar{K}$ (due to the fact that $f_0(980)$ is just below the $K\bar{K}$ threshold and it couples strongly to $K\bar{K}$) behaving as a large standing $S-$wave surrounding the relatively small $q\bar{q}$ core. We consider a model for heavy-light meson decays, the Constituent Quark Meson Model (CQM) [13], so far successfully applied, and see if it predicts the decay rates for $D_s \to \phi\pi$ and $f_0(980)\pi$ compatible with the recent data. The CQM has been widely exploited for heavy-light meson decays, in which the light quarks are u or d. Recently some of us [14] studied $D \to \sigma\pi \to 3\pi$ with the CQM, finding good agreement with the E791 data for this process and assuming the σ is predominantly $(u\bar{u} + d\bar{d})/\sqrt{2}$. The role of the σ in B decays to 3 pions was also investigated [15].

In a recent paper by Anisovich *et al.*, the authors adopt the hypothesis of an $f_0(980)$ having $s\bar{s}$ and $(u\bar{u} + d\bar{d})/\sqrt{2}$ components with a mixing angle of -48^o deduced from a phenomenological analysis of $\phi(1020) \to \gamma f_0(980), \gamma\eta, \gamma\eta', \gamma\pi^0$

and $f_0(980) \to \gamma\gamma$ radiative decays [16]. The $K\bar{K}$ component of $f_0(980)$ is neglected in this approach. On the other hand it has been shown by Markushin [17] how a $K\bar{K}$ molecular picture of $f_0(980)$ can explain the $f_0(980) \to \pi\pi$ decay with no need of $u\bar{u}, d\bar{d}$ components. As we shall see, our analysis favors a $f_0(980)$ produced as an $s\bar{s}$ state which evolves generating a virtual cloud of $K\bar{K}$ eventually decaying in an OZI allowed way to $\pi\pi$, as shown in Fig. 1. In fact we shall test the hypothesis that the $s\bar{s}$ component is substantial.

(ii) $D_s \to f_0\pi$

The CQM model can be extended in the strange quark sector solving the *gap equation* discussed in [18] with a non zero current mass for the strange quark:

$$\Pi(m) = m - m_0 - 8mGI_1(m^2) = 0, \tag{1}$$

where $G = 5.25$ GeV^{-2} and m_0 is the current mass of the strange quark. The I_1 integral is calculated using the proper time regularization:

$$I_1 = \frac{iN_c}{16\pi^4}\int^{reg}\frac{d^4k}{(k^2-m^2)} = \frac{N_c m^2}{16\pi^2}\Gamma\left(-1,\frac{m^2}{\Lambda^2},\frac{m^2}{\mu^2}\right). \tag{2}$$

The choice of the UV cutoff is dictated by the scale of chiral symmetry breaking $\Lambda_\chi = 4\pi f_\pi$ [19] and we adopt $\Lambda = 1.25$ GeV. The IR cutoff μ and the constituent mass m must be fixed taking into account that CQM does not incorporate confinement. This means that we have to enforce the kinematical condition to produce free constituent quarks $M \geq m_Q + m$, where M is the mass of the heavy meson and m_Q is the constituent mass of the heavy quark there contained. Considering that the heavy meson momentum is $P^\mu = m_Q v^\mu + k^\mu$, v^μ being the heavy quark 4-velocity and k^μ the so called residual momentum due to the interactions of the heavy quark with the light degrees of freedom at the scale of $\Lambda_{\rm QCD}$, the above condition coincides with $v\cdot k \geq m$ (since $P = Mv$, the 4-velocity of the meson is almost entirely carried by the heavy quark), or equivalently, in the rest frame of the meson, $\inf(k) = m$, meaning that the smallest residual momenta that can run in the CQM loop amplitudes are of the same size of the light constituent mass. The IR cutoff μ is therefore $\mu \simeq m$.

A reasonable constituent quark mass for the strange quark is certainly $m = 510$ MeV, considering the ϕ meson as a pure $s\bar{s}$ state [8]. Taking $\mu = 0.51$ GeV as an infrared cutoff, a value of $m_0 = 131$ MeV, see Fig. 2, is required by the gap equation (consistently with the spread of values for the current s quark mass quoted into [8]). Varying the current strange mass in the range $60-170$ MeV reflects into a small excursion of the constituent strange mass around the 500 MeV value.

The free parameter of CQM is Δ_H defined by $\Delta_H = M_H - m_Q$. The subscript H refers to the $H-$multiplet of Heavy-Quark-Effective-Theory (HQET) [20] $H = (0^-, 1^-)$. In a similar way a Δ_S is associated to the S multiplet, $S = (0^+, 1^+)$. The latter is determined fixing Δ_H [18]. The related Δ_H, Δ_S values in the strange sector are shown in Table I. We consider the range of values $\Delta_H = 0.5, 0.6, 0.7$ GeV in all numerical computations. This range is consistent with the condition $M \geq m_Q + m$.

As a first test we compute the decay constant f_{D_s} given in CQM by the following expression:

$$f_{D_s} = \frac{\hat{F}}{\sqrt{m_H}} = \frac{2\sqrt{Z_H}(I_1 + (\Delta_H + m)I_3(\Delta_H))}{\sqrt{m_H}}, \tag{3}$$

where $m_H = m_{D_s} = 1.968$ GeV and:

$$\begin{aligned} I_3(\Delta) &= -\frac{iN_c}{16\pi^4}\int^{\rm reg}\frac{d^4l}{(l^2-m^2)(v\cdot l + \Delta + i\epsilon)} \\ &= \frac{N_c}{16\,\pi^{3/2}}\int_{1/\Lambda^2}^{1/\mu^2}\frac{ds}{s^{3/2}}\, e^{-s(m^2-\Delta^2)}\,\left(1+{\rm erf}(\Delta\sqrt{s})\right). \end{aligned} \tag{4}$$

The renormalization constant Z_H is given by:

$$Z_H^{-1} = (\Delta_H + m)\frac{\partial I_3(\Delta_H)}{\partial \Delta_H} + I_3(\Delta_H). \tag{5}$$

Numerically we find:

$$f_{D_s} = 297^{+29}_{-22}\ {\rm MeV}, \tag{6}$$

(the error is computed varying Δ_H in the range of values quoted above) that is in good agreement with the value in the PDG [8]:

$$f_{D_s} = 280 \pm 19 \pm 28 \pm 34 \text{ MeV}. \tag{7}$$

Let us now consider the $D_s \to f_0(980)$ semileptonic amplitude:

$$\begin{aligned}\langle f_0(q_{f_0})|A^\mu_{(\bar{s}c)}(q)|D_s(p)\rangle &= \left[(p+q_{f_0})^\mu + \frac{m^2_{f_0} - m^2_{D_s}}{q^2} q^\mu\right] F_1(q^2) \\ &- \left[\frac{m^2_{f_0} - m^2_{D_s}}{q^2} q^\mu\right] F_0(q^2),\end{aligned} \tag{8}$$

with $F_1(0) = F_0(0)$. This amplitude can be represented by the diagram in Fig. 3. CQM allows to model the f_0 vertex, indicated with a black spot, through the diagrams in Figs. 4 and 5 respectively. The former gives what we call the *polar* contribution to the form factors: considering the 0^- intermediate polar state one can compute F_0 while 1^+ is connected to F_1. The *direct* diagram, depicted in Fig. 5, gives access to both the computation of F_1 and F_0. The method and the computation technique have been fully explained in [14]. Actually, in a factorization scheme, the amplitude describing the decay $D_s \to f_0(980)\pi$ is expressed by the product of two matrix elements. One is the semileptonic matrix element (8), the other is the well known:

$$\langle \pi|A^\mu_{(\bar{u}d)}(q)|\text{VAC}\rangle = i f_\pi q^\mu. \tag{9}$$

The q^μ in this matrix element selects F_0 as the relevant form factor for the computation of the amplitude. The polar and direct contributions to the form factors must be added in order to determine $F_0(q^2 = m^2_\pi \simeq 0)$. In the case at hand we use a coupling of $f_0(980)$ to the light quarks that, for SU_3-flavor symmetry, is $g_{f_0 ss} = \sqrt{2} g_{\sigma qq} = 2.49\sqrt{2}$ [21]. This of course comes from the hypothesis of an $f_0(980)$ having a $\bar{s}s$ structure. If on the other hand one would adopt the picture given in [16], $g_{f_0 ss}$ should be reduced by a factor of $\sin(\phi)$, with $\phi = -48^o$. The numerical value for F_0 is obtained through the CQM expressions containing the $I_i(\Delta_H)$ and $I_i(\Delta_S)$ integrals discussed in [14]. The result is the following:

$$F_0(q^2 = 0) = F_0^{(\text{pol})}(0) + F_0^{(\text{dir})}(0) = 0.64^{+0.05}_{-0.03}. \tag{10}$$

The expression for the decay amplitude is:

$$g_{D_s f_0 \pi} = \langle f_0 \pi^+|H_{\text{eff}}|D_s^+\rangle = \frac{G_F}{\sqrt{2}} V^*_{cs} V_{ud} a_1 F_0(0)(m^2_{D_s} - m^2_{f_0}) f_\pi, \tag{11}$$

where H_{eff} is the effective Hamiltonian of Bauer, Stech and Wirbel [22], with $a_1 = 1.10 \pm 0.05$ fitted for D decays [23]. Its numerical value is:

$$g_{D_s f_0 \pi} = (2.08^{+0.16}_{-0.12}) \times 10^{-6} \text{ GeV}, \tag{12}$$

and therefore the predicted width is:

$$\Gamma(D_s^+ \to f_0(980)\pi^+) = \frac{g^2_{D_s f_0 \pi}}{16\pi m^3_{D_s}} \sqrt{\lambda(m^2_{D_s}, m^2_{f_0}, m^2_\pi)} = (3.27^{+0.52}_{-0.35}) \times 10^{-14} \text{ GeV}, \tag{13}$$

(λ is the triangular function), to be compared with the PDG [8] one:

$$\Gamma(D_s^+ \to f_0(980)\pi^+) = (2.39 \pm 1.06) \times 10^{-14} \text{ GeV}. \tag{14}$$

Considering the mixing of $s\bar{s}$ with the $(u\bar{u} + d\bar{d})/\sqrt{2}$ component, i.e., using the reduced coupling $g_{f_0 ss}\sqrt{2}\sin(\phi)$ discussed above, one would obtain a different prediction for the width:

$$\Gamma(D_s \to f_0(980)\pi) = (1.86^{+0.28}_{-0.25}) \times 10^{-14}. \tag{15}$$

Even if (13) and (15) seem both to agree with the experimental value (14), for reasons that will be explained soon, the CQM model definitely favors the $s\bar{s}$ scenario.

In order to make a comparison with E791 results [11], we compute the branching ratio $\mathcal{B}(D_s^+ \to f_0(980)\pi^+ \to 3\pi)$ estimating the coupling $g_{f_0\pi^+\pi^-}$ for $f_0 \to \pi^+\pi^-$ through the following formula:

$$\frac{g^2_{f_0\pi^+\pi^-}}{4\pi} = \frac{2m^2_{f_0} C\Gamma_0}{\sqrt{m^2_{f_0}/4 - m^2_\pi}}, \tag{16}$$

where $C = 2/3 \times 0.68 \simeq 4/9$ is the fraction of the total $f_0(980)$ width related to the process $f_0 \to \pi^+\pi^-$ (the $K\bar{K}$ decay mode is also considered, 2/3 being the isospin factor and $0.68 = \Gamma(f_0 \to \pi\pi)/(\Gamma(f_0 \to \pi\pi) + \Gamma(f_0 \to K\bar{K}))$ [8]) and $\Gamma_0 = 44$ MeV is the central value of the width of $f_0(980)$ found by E791 [11]. Using the expression:

$$\Gamma(D_s^+ \to f_0(980)\pi^+ \to 3\pi) = \frac{1}{2}\int_{4m_\pi^2}^{(m_{D_s}-m_\pi)^2} ds\, \Gamma_{D_s \to f_0\pi}(s) \times \frac{1}{\pi}\frac{\sqrt{s}\Gamma_{f_0\to\pi^+\pi^-}(s)}{(s-m^2_{f_0})^2 + m^2_{f_0}\Gamma^2_{f_0}(s)}, \tag{17}$$

where the Γ's are computed assuming a pure $s\bar{s}$ component in production as in (13) but substituting $m^2_{f_0} \to s$, and the co-moving width is:

$$\Gamma_{f_0}(s) = \Gamma_0 \times \frac{m_{f_0}}{\sqrt{s}} \frac{\sqrt{s/4 - m^2_\pi}}{\sqrt{m^2_{f_0}/4 - m^2_\pi}}. \tag{18}$$

Assuming the E791 value $m_{f_0} = 975$ MeV [11] and taking the central value of the PDG branching ratio $\mathcal{B}(D_s \to 3\pi) = 1.0\%$ (disregarding the large given uncertainty ± 0.4) one finds that the fraction of D_s decaying into 3π via $f_0(980)$ is given by:

$$\mathcal{B}(D_s^+ \to f_0(980)\pi^+ \to 3\pi) = 50^{+8}_{-6}\ \%. \tag{19}$$

This turns out to be in good agreement with the E791 results [11]:

$$\mathcal{B}(D_s^+ \to f_0(980)\pi^+ \to 3\pi) = (56.5 \pm 4.3 \pm 4.7)\ \%, \tag{20}$$

as far as the central value of the experimental branching ratio $\mathcal{B}(D_s \to 3\pi)$ is concerned. Unfortunately the lack of precision in this measurement weakens the comparison between the CQM calculation and the E791 results.

(iii) $D_s \to \phi\pi$

In order to overcome the ambiguity between what found in the pure $s\bar{s}$ hypothesis and in the case of an $f_0(980)$ pictured as a mixture of $s\bar{s}$ and $(u\bar{u}+d\bar{d})/\sqrt{2}$ (both results (13) and (15) seem to be consistent with the experimental value (14)) we consider the CQM analysis of the $D_s \to \phi\pi$ decay in order to compare the widths $\Gamma(D_s \to \phi\pi)$ and $\Gamma(D_s \to f_0\pi)$. We believe that the ratio $\Gamma(D_s \to f_0\pi)/\Gamma(D_s \to \phi\pi)$ is the most reliable theoretical output of our approach to be compared with experimental data since it is less dependent on CQM parameters and experimental normalizations. We will find that also the $\Gamma(D_s \to \phi\pi)$ turns out to be larger with respect to the experimental one, analogously to what found in (13) with respect to (14). Interestingly the ratio of the two widths is in very good agreement with the experimental ratio. This agreement is instead destroyed if a large mixing with $u\bar{u}$ and $d\bar{d}$ components is taken into account.

Considering the $\phi(1020)$ as an $\bar{s}s$ state, we can again make use of factorization hypothesis [22] to compute the $D_s \to \phi\pi$ amplitude. The semileptonic form factors are defined by:

$$\begin{aligned}\langle\phi(\epsilon,p')|A^\mu_{(\bar{s}c)}(q)|D_s^+(p)\rangle &= (m_{D_s}+m_\phi)A_1(q^2)\epsilon^{*\mu} \\ -\frac{(\epsilon^*\cdot q)}{(m_{D_s}+m_\phi)}(p+p')^\mu A_2(q^2) &- (\epsilon^*\cdot q)\frac{2m_\phi}{q^2}q^\mu(A_3(q^2)-A_0(q^2)).\end{aligned} \tag{21}$$

To avoid the singularity in $q^2 = 0$, the condition:

$$A_0(0) = A_3(0), \tag{22}$$

must hold. Moreover:

$$A_3(q^2) = \frac{m_{D_s}+m_\phi}{2m_\phi}A_1(q^2) - \frac{m_{D_s}-m_\phi}{2m_\phi}A_2(q^2). \tag{23}$$

Observing that $q = (p - p')$ and using eq. (9) one obtains:

$$g_{D_s\phi\pi} = \langle \phi\pi^+ | H_{\text{eff}} | D_s^+ \rangle = \frac{G_F}{\sqrt{2}} V_{cs}^* V_{ud} a_1 A_0(m_\pi^2) 2m_\phi (\epsilon^* \cdot q) f_\pi. \tag{24}$$

In order to compute the width, a sum over final ϕ polarizations is performed. The form factor $A_0(0)$ can be computed with CQM following the approach outlined in [24]. There is a *direct* and a *polar* contribution to the form factors, as in the diagrams in Figs. 4,5. The ϕ particle attached to the loop is introduced, via Vector-Meson-Dominance (VMD), through an interpolating current:

$$J_\mu = \frac{m_\phi^2}{c_\phi f_\phi} \gamma_\mu, \tag{25}$$

where the leptonic decay constant f_ϕ is defined by:

$$\langle \text{VAC} | V_\mu | \phi(\epsilon) \rangle = f_\phi \epsilon_\mu, \tag{26}$$

with $V_\mu = -\bar{s}\gamma_\mu s$, and:

$$c_\phi = \frac{1}{\sqrt{6}} \cos(\theta_{\phi\omega}), \tag{27}$$

$\theta_{\phi\omega} = 39.4^o$ being the $\phi - \omega$ mixing angle, see e.g. [25]. This current appears in the CQM loop integral calculation in correspondence of the vertex (light quark)-(ϕ)-(light quark). The lepton decay constant f_ϕ can be extracted from the value of the width:

$$\Gamma(\phi \to e^+ e^-) = \frac{4\pi\alpha^2}{3} \left(\frac{f_\phi c_\phi}{m_\phi^2} \right)^2 m_\phi, \tag{28}$$

(as is checked with a straightforward calculation), given in the PDG [8]. We will use the value $f_\phi = 249$ MeV^2.

Following [24], the direct contribution to $A_0(0)$ is given by:

$$\begin{aligned} A_0^{\text{dir}}(q^2 = 0) = -\frac{m_\phi}{f_\phi c_\phi} \sqrt{Z_H m_{D_s}} \Bigg[& \Omega_1 \left(m_\phi \bar{\omega} - \frac{r_1}{m_{D_s}} \right) + m_\phi \Omega_2 + \\ & 2\Omega_3 + \Omega_4 + \Omega_5 + 2\Omega_6 \left(\bar{\omega} - \frac{r_1}{m_{D_s} m_\phi} \right) - \\ & Z \left(m^2 - m \frac{r_1}{m_{D_s}} + m m_\phi \bar{\omega} \right) \Bigg], \end{aligned} \tag{29}$$

where:

$$\begin{aligned} \bar{\omega} &= \frac{m_{D_s}^2 + m_\phi^2}{2 m_{D_s} m_\phi} \\ r_1 &= \frac{m_{D_s}^2 - m_\phi^2}{2}, \end{aligned}$$

and the integrals Z, Ω_j, which are functions of Δ_1, Δ_2, x and $\bar{\omega}$, are tabulated in [24] and computed using $x = m_\phi$, the $\bar{\omega}$ given above and the Δ_H values from Table I. Δ_2 are here substituted by $\Delta_H - m_\phi \bar{\omega}$. The polar form factors needed to compute $A_0^{\text{pol}}(q^2 = 0)$ are, according to eqs. (22) and (23) , $A_1^{\text{pol}}(0)$ and $A_2^{\text{pol}}(0)$, given respectively by [24]:

$$A_1^{\text{pol}}(0) = \frac{\sqrt{2 m_{D_s}} g_V \hat{F}^+}{m_{D_s(1^+)} (m_{D_s} + m_\phi)} (\zeta - 2\mu \bar{\omega} m_\phi) \tag{30}$$

$$A_2^{\text{pol}}(0) = -\sqrt{2} g_V \mu \hat{F}^+ \frac{\sqrt{m_{D_s}} (m_{D_s} + m_\phi)}{m_{D_s(1^+)}^2}, \tag{31}$$

where now $\bar{\omega} = \frac{m_{D_s}}{2 m_\phi}$, $g_V = \frac{m_\phi}{f_\pi}$ and $\hat{F}^+$ is defined by:

$$\langle \mathrm{VAC}|A_\mu|D_s(1^+)\rangle = i\sqrt{m_{D_s(1^+)}}v^\mu \hat{F}^+, \tag{32}$$

and computed in analogy with (3), see [18]. The ζ and μ strong coupling constants are described in [24]:

$$\mu = \frac{m_\phi^2}{\sqrt{2}g_V f_\phi c_\phi}\sqrt{Z_H Z_S}\left(-\Omega_1 - 2\frac{\Omega_6}{m_\phi} + mZ\right) \tag{33}$$

$$\zeta = \frac{\sqrt{2}m_\phi^2}{g_V f_\phi c_\phi}\sqrt{Z_H Z_S}\left(m_\phi\Omega_2 + 2\Omega_3 + \Omega_4 + \Omega_5 - m^2 Z\right), \tag{34}$$

where the Ω_j integrals involved are functions of $\Delta_1 = \Delta_H$, $\Delta_2 = \Delta_S$, $x = m_\phi$ and $\omega = (\Delta_1 - \Delta_2)/m_\phi$. The renormalization constant Z_S is defined by:

$$Z_S^{-1} = (\Delta_S - m)\frac{\partial I_3(\Delta_S)}{\partial \Delta_S} + I_3(\Delta_S). \tag{35}$$

Of course everywhere $m = 510$ MeV is the constituent mass of the strange quark. μ and ζ are affected by a considerable uncertainty due to varying Δ_H in the range of Table I; this is reflected in a large uncertainty in the polar form factor $A_0^{\mathrm{pol}}(0) = -0.16^{+0.27}_{-0.2}$. The direct form factor is instead more stable against Δ_H variations being $A_0^{\mathrm{dir}}(0) = 1.26^{+0.19}_{-0.15}$. Considering that:

$$A_0(0) = A_0^{\mathrm{pol}}(0) + A_0^{\mathrm{dir}}(0), \tag{36}$$

we can readily compute the CQM ratio of widths in the case of only $s\bar{s}$ in the production:

$$R = \frac{\Gamma(D_s^+ \to f_0\pi^+)}{\Gamma(D_s^+ \to \phi\pi^+)} = 0.4 \pm 0.21, \tag{37}$$

to be compared with the PDG one [8]:

$$R = \frac{\Gamma(D_s^+ \to f_0\pi^+)}{\Gamma(D_s^+ \to \phi\pi^+)} = 0.49 \pm 0.20. \tag{38}$$

(iv) Conclusions

If one adopts the hypothesis of Anisovich *et al.*, the ratio R would be reduced to $R = 0.22 \pm 0.12$. E791 also measures the ratio $\Gamma(D_s \to 3\pi)/\Gamma(D_s \to f_0(980)\pi) = 0.245$ [11] with a very small uncertainty. If one considers (17) in the limit of narrow width for $f_0(980)$, one obtains $\Gamma(D_s \to f_0(980)\pi \to 3\pi) = C\,\Gamma(D_s \to f_0(980)\pi)$ (see the discussion after eq.16). On the other hand E791 finds that $\Gamma(D_s \to f_0(980)\pi \to 3\pi) = 56.5\%\Gamma(D_s \to 3\pi)$ or, in other words, they measure $R = 0.62$ with a very small error. This indeed agrees with the known PDG result (38).

The computed widths $D_s \to f_0\pi$ and $D_s \to \phi\pi$ are both larger with respect to the corresponding experimental values, nevertheless their ratio is only 20% smaller than the experimentally estimated ratio. Our results favor the scenario of an $f_0(980)$ made of an $s\bar{s}$ core surrounded by a standing S-wave of virtual $K\bar{K}$. A large $u\bar{u}$, $d\bar{d}$ component in $f_0(980)$ seems also excluded by the fact that in $D \to 3\pi$ decays the $f_0(980)$ is weakly produced [10].

Therefore, in conclusion, our work supports a description of $f_0(980)$ as $s\bar{s}$, with virtual $K\bar{K}$ cloud. Any substantial mixture of $u\bar{u}$, $d\bar{d}$ seems excluded. Light-quark phenomenology has been fighting since a long time to understand the scalar mesons. It now appears that heavy meson decays may be able to clarify this difficult problem: *nemo propheta in patria.*

ACKNOWLEDGMENTS

ADP and NAT acknowledge support from EU-TMR program, contract CT98-0169.

---

[1] N. A. Törnqvist and M. Roos, Phys. Rev. Lett. **76**, 1575 (1996) [hep-ph/9511210]; N. A. Törnqvist, Z. Phys. **C68**, 647 (1995) [hep-ph/9504372]; M. Boglione and M. R. Pennington, Phys. Rev. Lett. **79**, 1998 (1997) [hep-ph/9703257]; E. Van Beveren, T. A. Rijken, K. Metzger, C. Dullemond, G. Rupp and J. E. Ribeiro, Z. Phys. **C30**, 615 (1986).

[2] J. A. Oller, E. Oset and J. R. Pelaez, Phys. Rev. Lett. **80**, 3452 (1998) [hep-ph/9803242]; Phys. Rev. **D59**, 074001 (1999) [hep-ph/9804209], Erratum-ibid. **D60**, 099906 (1999).

[3] J. Weinstein and N. Isgur, Phys. Rev. Lett. **48**, 659 (1982); Phys. Rev. **D41**, 2236 (1990).

[4] R. Jaffe, Phys. Rev. **D15**, 267 (1977); see also N. N. Achasov, Nucl. Phys. **A675**, 279 (2000) [hep-ph/9910540].

[5] P. Minkowski and W. Ochs, Eur. Phys. J. **C9**, 283 (1999) [hep-ph/9811518].

[6] F. E. Close and A. Kirk, Phys. Lett. **B483**, 345 (2000) [hep-ph/0004241].

[7] R. M. Barnett *et al.*, "Review of particle physics. Particle Data Group", Phys. Rev. **D54**, 1 (1996).

[8] D. E. Groom *et al.*, "Review of particle physics. Particle Data Group," Eur. Phys. J. **C15**, 1 (2000).

[9] *"Possible existence of the light σ resonance and its implication to hadron physics"*, Yukawa institute, Kyoto, Japan, June 11-14,2000, (KEK-proceedings/2000-4), see also N. A. Törnqvist, "Summary talk of the conference on the sigma resonance", hep-ph/0008135.

[10] E. M. Aitala *et al.* [E791 Collaboration], "Experimental evidence for a light and broad scalar resonance in $D^+ \to \pi^-\pi^+\pi^+$ decay", hep-ex/0007028; see also C. Gobel [E791 Collaboration], hep-ex/0012009.

[11] E. M. Aitala *et al.* [E791 Collaboration], "Study of the $D_s^+ \to \pi^-\pi^+\pi^+$ decay and measurement of f_0 masses and widths", hep-ex/0007027.

[12] V. M. Aulchenko *et al.* [SND Collaboration], Phys. Lett. **B440**, 442 (1998) [hep-ex/9807016].

[13] A. Deandrea, N. Di Bartolomeo, R. Gatto, G. Nardulli and A. D. Polosa, Phys. Rev. **D58**, 034004 (1998) [hep-ph/9802308]; A. Deandrea, in *ICHEP 98, High energy physics, vol. 2, 1179-1183*, hep-ph/9809393; A. Deandrea, R. Gatto, G. Nardulli and A. D. Polosa, JHEP **9902**, 021 (1999) [hep-ph/9901266]. A. Deandrea, in the *proceedings of 34th Rencontres de Moriond, Les Arcs, France, 20-27 Mar 1999*, hep-ph/9905355. A. D. Polosa, in *Frontiers of Matter, Chateau de Blois, France, 28 Jun - 3 Jul 1999*, hep-ph/9909371.

[14] R. Gatto, G. Nardulli, A. D. Polosa and N. A. Törnqvist, Phys. Lett. **B494**, 168 (2000).

[15] A. Deandrea and A. D. Polosa, "$B \to \rho\pi$ decays, resonant and nonresonant contributions", hep-ph/0008084, to appear in Phys. Rev. Lett.

[16] A. V. Anisovich, V. V. Anisovich and V. A. Nikonov, hep-ph/0011191.

[17] V. E. Markushin, Eur. Phys. J. **A8**, 389 (2000) [hep-ph/0005164].

[18] A. D. Polosa, "The CQM model", hep-ph/0004183, to appear in La Riv. del Nuovo Cimento Vol. 23, N. 11 (2000).

[19] H. Georgi, *Weak Interactions and Modern Particle Theory*, Addison-Wesley, 1984.

[20] A. Manohar and M. Wise, *Heavy Quark Physics*, Cambridge, 2000.

[21] D. Ebert and M. K. Volkov, Z. Phys. **C16**, 205 (1983); D. Ebert, "Bosonization in particle physics", hep-ph/9710511.

[22] M. Bauer, B. Stech and M. Wirbel, Z. Phys. **C34**, 103 (1987).

[23] A. Deandrea, N. Di Bartolomeo, R. Gatto and G. Nardulli, Phys. Lett. **B318**, 549 (1993) [hep-ph/9308210].

[24] A. Deandrea, R. Gatto, G. Nardulli and A. D. Polosa, Phys. Rev. **D59**, 074012 (1999) [hep-ph/9811259].

[25] R. Escribano and J. M. Frere, Phys. Lett. **B459**, 288 (1999) [hep-ph/9901405].

Δ_H	Δ_S
0.5	0.86
0.6	0.91
0.7	0.97

TABLE I. Δ values in (in GeV)

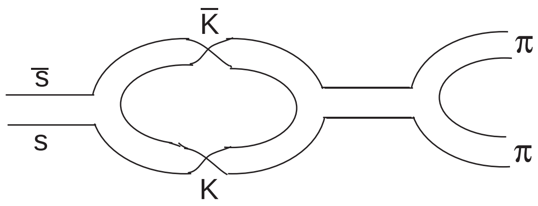

Fig. 1 - After the production at short distances in D_s decay via its $s\bar{s}$ component (see Figs. 3-5), the $f_0(980)$, being just below the $K\bar{K}$ threshold, evolves in time generating a substantial $K\bar{K}$ component (with larger spatial dimension than $s\bar{s}$) that can decay, in OZI allowed way, to 2π.

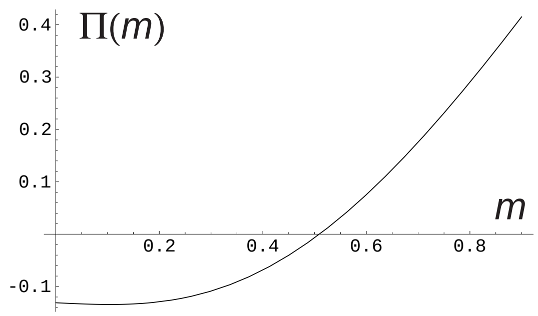

Fig. 2 - Gap equation zero for a fixed value of m_0. The masses are expressed in GeV. Here $m_0 = 131$ MeV is the current mass of the *strange* quark.

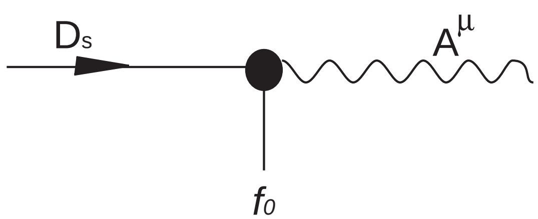

Fig. 3 - The semileptonic amplitude. The vertex with the weak current and the f_0 can be modeled with CQM as is described in Figs. 3 and 4. The same diagrams with ϕ in place of f_0 are also considered. The ϕ resonance is introduced, via VMD, through an interpolating current J_μ.

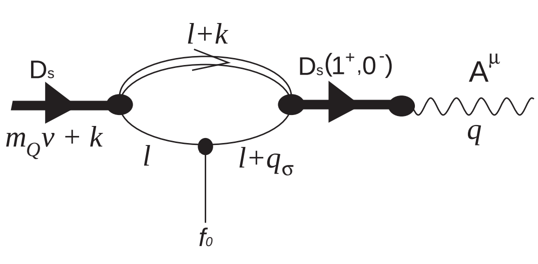

Fig. 4 - The *polar* diagram. The polar contribution to the form factor is reliable when computed near the pole mass. The uncertainty in the extrapolation $q^2 \to 0$ reflects in the violation of the condition $F_0^{\rm pol}(0) = F_1^{\rm pol}(0)$. This kind of uncertainty is taken into account in our calculation.

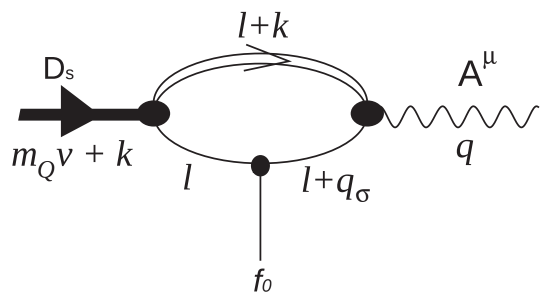

Fig. 5 - The *direct* diagram. The condition $F_0^{\rm dir}(0) = F_1^{\rm dir}(0)$, avoiding the spurious singularity in $q^2 = 0$ in (8), is automatically satisfied.